

# Chapter 16

## Contact Lenses for Physiological Studies



## Introduction

After the various publications describing the first clinical applications of contact lenses by *Fick*, *Sulzer* and *Dor* in the early years of the 20<sup>th</sup> century, it soon became evident that they could not be used for the correction of keratoconus. On the other hand, they represented an extraordinary scientific instrument for producing transient corneal neutralization and even creating artificial refractive errors.

This is how it came about that *Alfred Michel*, physician at the *Berne Ophthalmological Clinic*, used a contact lens to neutralize his own cornea in order to reproduce the earlier experiments on accommodation that had been carried out by *Woinow* with the orthoscope. (1)

The engineers and opticians of *Carl Zeiss* (Jena, Germany), the most reputed manufacturer of optical lenses at that time, followed closely those scientific advances relating to optics and ophthalmology. They attended ophthalmological congresses and participated in debates on any optical question under discussion. There is evidence of this interest in the publication dating from 1912 of a series of studies on physiological optics and, in particular, on the correction of anisometropia after cataract extraction. The optical industry was confronted with the failures of “anisometric spectacle glasses”. In order to reproduce refractive errors artificially and thus reconstruct the conditions under which the prescribed glasses could be used, the researchers had the idea of using contact lenses specially ground for this purpose.

These experimental conditions revealed an undoubted interest in the theory of correction by contacts and were definitely useful for the later development of this method of correction. After all, the experiments had their origin in Jena and were performed both by the engineer *von Rohr* and by physicians at the *University Eye Clinic in Jena*, namely Professor *Stock* and his assistants *Erggelet* and *Ishihara*.

# 1 - Source documents

<b>Year</b>	<b>Publication</b>
1892	Michel: "Zur Frage der ungleichmässigen Accommodation" (Contribution to the Question of irregular Accommodation) - doctoral thesis
1893	Michel: "Beitrag zur Frage der Akkommodation" (Contribution to the Question of Accommodation)
1912	Stock: "Ueber eine neue Verwendungsart der von Fick angegebenen Kontaktbrillen" (Concerning a new Application for the 'Kontaktbrille' introduced by Fick)
1912/13	Rohr & Stock: "Ueber eine Methode zur subjektiven Prüfung von Brillenwirkungen" (Concerning a Method for the subjective Assessment of the Effects of Spectacle glasses)
1913	Rohr & Stock "Ueber eine Methode zur subjektiven Prüfung von Brillenwirkungen" (Concerning a Method for the subjective Assessment of the Effects of Spectacle glasses)
1913/14	Erggelet: "Zur Korrektion der einseitigen Aphakie" (Concerning the Correction of Unilateral Aphakia)
1914	Erggelet: "Die Bedeutung der Fick'schen Kontaktgläser für Beurteilung des beidäugigen Sehens durch Brillengläser" (The Significance of Fick's Contact glasses for the Assessment of Binocular Vision by means of Spectacle glasses)
1914	Ishihara: "Warum können Anisometropen höheren Grades in der Regel die vollkorrigierten Gläser nicht ertragen?" (Why can higher-level Anisometropes generally not tolerate their full Glasses Correction?)
1916	Erggelet: "Ein Beitrag zur Frage der Anisometropie" (A Contribution concerning the Question of Anisometropia)
1921	Erggelet: "Versuche zur beidäugigen Tiefenwahrnehmung bei hoher Ungleichsichtigkeit" (Experiments on Binocular depth Perception in cases of Severe Anisometropia)
1922	Rohr: "On the Available Means for Correcting Cases of Considerable Anisometropia"
1925	Ishihara (in Japanese): "Note on spectacle prescription for anisometropia"

Table 16 - 1

Chronology of the principal publications between 1893 and 1925 dedicated to the study of physiological optics and carried out with ground-glass corneal contact lenses.

## 1.1 – The Study on Accommodation by Michel (1893).

Following the leading publications of 1888, contact lenses were recommended for studies in physiological optics. Thus, *Michel* used contact lenses for his studies on accommodation at the *Berne Ophthalmological Clinic* in 1892. At this time, the question of whether the crystalline lens could produce, by means of partial and selective contraction of the ciliary muscle, sufficient cylindrical accommodation to compensate for corneal astigmatism remained an open question. *Woinow* had already demonstrated the absence of this cylindrical accommodation by ensuring corneal neutralization with an orthoscope, but a complex apparatus in which the water bath produced a hypermetropia capable of distorting the

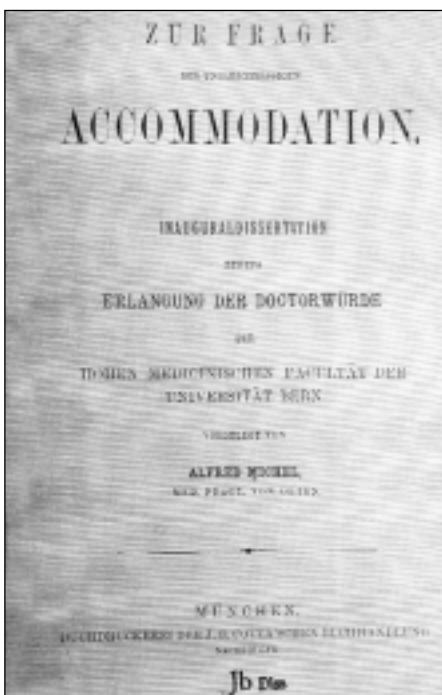


Figure 16-1

Front page of the "Inaugural Dissertation" for doctorate in medicine of Alfred Michel (1892) concerning the use of contact lenses for studying accommodation.

In his doctoral thesis: "Zur Frage der ungleichmässigen Accommodation" (Contribution to the Question of irregular Accommodation), Alfred Michel of Berne (Switzerland), describes the use of contact lenses to neutralize possible corneal accommodation.

(MICHEL Alfred Zur Frage der ungleichmässigen Accommodation, Inaugural Dissertation Bern, Cotta, München, 1892)

experiments was necessary. *Michel* repeated these experiments by ensuring, on this occasion, the neutralization of corneal refractive power by means of contact lenses. He presented these studies in his “Inaugural Dissertation” in 1892 under the title “*Zur Frage der ungleichmässigen Accommodation*” (*Concerning the Question of Irregular Accommodation*) and in 1893 in the publication “*Beitrag zur Frage der Accommodation*” (*Contribution to the Question of Accommodation*). In the introduction, *Michel* announces the utilization of contact lenses as a substitute for *Woinow*’s orthoscope. The reference to *Sulzer*’s contact lenses is a short one:

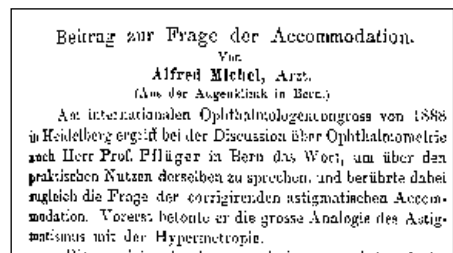


Figure 16-2  
Alfred Michel's publication on the utilization of contact lenses for the study of accommodation. In his publication, "Beitrag zur Frage der Akkommodation" (Contribution to the Question of Accommodation), Alfred Michel of Berne (Switzerland) describes the use of contact lenses to neutralize possible corneal accommodation. (MICHEL Alfred, "Zur Frage der ungleichmässigen Accommodation" *Klinische Monatsblätter für Augenheilkunde*, 31, 1893, 223-250 & 267-297 - Excerpt of page 223)

*"Whereas Woinow made use of the orthoscope in order to eliminate the effect of the cornea in his experiments, I achieved the same goal by equipping my own eye with a Sulzer contact glass. I did this based on Professor Pflüger's advice. This experiment was not only more modern but was also less tiresome and difficult to carry out than the former."*

*"Wenn Woinow sich des Orthoskops bediente, um bei seinen Versuchen die Wirkung der Hornhaut auszuschliessen, so erreichte ich denselben Zweck dadurch, dass ich auf den Rath von Herrn Professor Pflüger mein Auge mit einem Sulzer'schen Contactglas bewaffnete, ein Verfahren, das nicht nur viel moderner, sondern auch nicht so mühselig und so schwierig in der Ausführung ist wie das erstere."* (2)

For this suggestion, *Michel* was indebted to Professor *Pflüger* of Berne, who possessed such a contact lens that had been manufactured by *Strübin* in Basle: *"A welcome alternative to Woinow's orthoscope that I tried three times without success is represented by Sulzer's contact lens. This was manufactured by Strübin of Basle and was placed at my disposal by Mr. Prof. Pflüger."* (3)

In the course of his work, *Michel* described the contact lens, its insertion into the eye, and the means of preventing the appearance of air bubbles:

*"Sulzer's contact lenses are finely ground glass shells that are filled with physiological saline solution and are placed on the cornea after it has been anesthetized with cocaine solution. The air bubbles that may appear between the cornea and glass are eliminated by pouring water in. In the place of the irregularly curved cornea, [...] there is substituted a mathematically known and unchanging surface of the contact glass."*

*"Die Sulzer'schen Contactgläser sind fein geschliffene Glasschalen, welche mit physiologischer Kochsalzlösung gefüllt und dann der durch Cocain anästhesierten Hornhaut aufgelegt werden. Eventuelle, zwischen Cornea und Glas liegende Luftblase werden durch Nachgiessen entfernt. An de Stelle der, [...] so unregelmässig gekrümmten Hornhaut ist so die mathematisch genau bekannte und unveränderliche Oberfläche des Contactglases getreten."* (4)

The ground contact lens that *Pflüger* had placed at *Michel*’s disposal possessed a “curvature of 32 diopters” that was much too high to correct his myopia of 2 diopters. However, this was not the aim of the research, as *Michel* only wanted to correct the corneal astigmatism by replacing the corneal surface irregularity with the regular curvature of the front surface of the contact lens:

*"If I had wished to correct with a contact glass my myopia of 2 diopters, I would have had to deduct these*

two diopters from the 40 diopters of my corneal refraction then take a glass with a refraction of 38 diopters. With the contact glass used at the time of the experiments, which was originally destined for the correction of irregular astigmatism of a very myopic eye, I became strongly hyperopic and I got back my normal vision of 1.5 only after placing a sphere of +6 in front. The glass therefore possessed a refractive power of 32 diopters.”

“Wollte ich meine Myopie von 2 D mit einem Contactglas corrigieren, so müsse ich jene 2 D von den 40 D meiner Hornhautrefraktion abziehen, also ein Glas von 38 D Brechkraft nehmen. Mit dem Contactglas, dessen ich mich bei den Versuchen [...] bediente, und welches ursprünglich zur Correction eines irregulären Astigmatismus eines stark myopen Auges bestimmte war, wurde ich stark hypermetrop und erreichte erst nach Vorsetzen von +6,0 sph. meinen normalen Visus von 1.5. Das Glas besass also 32 D Brechkraft.” (4)

The result obtained by *Michel* met his expectations; the corneal astigmatism was totally corrected:

“After the spherical contact glass had totally eliminated my physiological corneal astigmatism of 0.5 D, my compensatory perverse crystalline astigmatism became manifest. In fact, I was able to correct it totally with a concave cylinder of -0.5 with a vertical axis.”

“Nachdem mein physiologischer Hornhautastigmatismus von 0,5 D durch Vorsetzen eines absolut sphärischen Contactglases zum Verschwinden gebracht worden war, wurde mein compensatorischer perverser Linsenastigmatismus manifest. In der That, corrigierte ich den selben vollkommen mit einem Concavcylinder -0,5 Axe senkrecht.” (4)

In 1894, *Fick* confirms that it was the optician *Strübin* of Basle who had ground *Michel*'s contact lenses from one piece of glass and that they were of higher quality and less expensive than those recommended by *Sulzer* (5):

“Furthermore, Mr. Strubin now grinds small contact glasses from a single piece of glass that are, in my experience, more perfect and less expensive than those of the L Benoit [sic] company. Alfred Michel carried out his experiments with a Strubin glass.”

“Auch Herr Strübin in Basel schleift jetzt Contachgläschen aus einem Stücke, nach meiner Erfahrung vollkommener und billiger als das Haus L Benoît (sic). Alfred Michel hat seine Versuche mit einem Strübin'schen Glase angestellt.” (6)

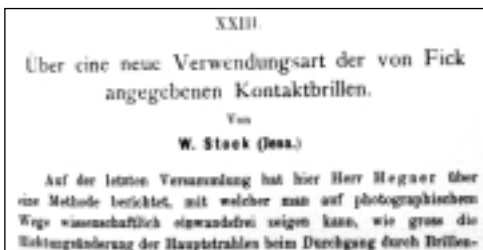


Figure 16-3

Stock's publication on anisometropia artificially produced by a contact lens.

Publication by Wolfgang Stock, director of the Eye Clinic at Jena (Germany), of his communication to the Heidelberg Congress of Ophthalmology: "Über eine neue Verwendungsart der von Fick angegebenen Kontaktbrillen" (Concerning a new Application for the Kontaktbrille introduced by Fick). The author reports that he has produced an anisometropia with contact lenses destined to evaluate the effect of correction of this by glasses.

(STOCK Wolfgang. "Über eine neue Verwendungsart der von Fick angegebenen Kontaktbrillen". Bericht der Deutschen Ophthalmologischen Gesellschaft, 42, 1920, 352-354. - Excerpt of page 352)

## 1.2 – Stock and Rohr's Artificial Ametropia (1912/13)

In 1912, Professor *Stock*, Director of the *Jena University Eye Clinic*, presented to the *Heidelberg Congress of Ophthalmology* a preliminary communication on the production of artificial anisometropia entitled "**Über eine neue Verwendungsart der von Fick angegebenen Kontaktbrillen**" (A new Application for the 'contact-spectacles' introduced by Fick). The anisometropia was produced with "*Fick*'s contact glass" in order to evaluate the effect of correcting this by glasses of sufficient power:

*"I believe that, with the help and cooperation of Mr. von Rohr, we have found a way to allow us to introduce in a two-fold manner the results of the theory to the ophthalmologically trained observer. I refer specifically to an artificial anisometropia introduced by application of a suitable Fick contact glass and corrected by means of an appropriate spectacle lens."*

*"Ich glaube in Gemeinschaft mit Herrn von Rohr eine solche Methode gefunden zu haben, die es gestattet in doppelter Weise die Ergebnisse der Theorie dem ophthalmologischen geschulten Beobachter nahe zu bringen.*

*Es wird nämlich künstlich eine Anisometropie durch Anwendung eines geeigneten Fickschen Kontaktglases eingeführt und diese durch ein geeignetes Brillenglas korrigiert."* (7)

The communication from Heidelberg gave no technical details and referred the listener to a publication in press. The latter appeared in the same year, cosigned by *Stock* and by *von Rohr*, medical engineer and director of the *Zeiss Company*, respectively, entitled **"Über eine Methode zur subjektiven Prüfung von Brillenwirkungen"** (*Concerning a Method for the subjective Assessment of the Effects of Spectacle glasses*). (8)

### Contact-Lens-induced Artificial Anisometropia

In order to explain the effect of "anisometropia spectacles", as recommended by *von Rohr*, the authors created a unilateral ametropia on one side by means of a small contact lens *"in order to change the refraction of the optical system in the eye at will, without affecting the characteristic movement of the whole system around the ocular center of rotation"*. (9)

The failure of spectacle lenses to correct anisometropia was traditionally attributed to the difference in size of the retinal images, resulting from the magnifying loupe effect of one of the spectacle lenses. *Stock* and *von Rohr* showed from their experiments that the prismatic effect of spectacle lenses constituted a second obstacle to the fusion of perceived images. Quite apart from its interest in regard to the correction of anisometropia, this article takes evidence about the level of contemporary knowledge relating to contact lenses at that time.

### History of Contact Lenses

Assuming that their readers were uninformed, *von Rohr* and *Stock* added a historical introduction to their work: *"The more recent history of the 'Kontaktbrille' does not seem to be generally known; it is, however, so full of interest that it is well worthwhile to describe it to you in a few words."* (10)

The authors recall that *Fick* carried out contact lens fittings essentially for the correction of

(Mitteilung aus der Jenaer Augenklinik und der Zeiss'schen Werkstatt.)

#### Über eine Methode zur subjektiven Prüfung von Brillenwirkungen.

Von  
M. v. Rohr und W. Stock.

Mit 7 Figuren im Text.

Bei der Beurteilung der Wirkung von Brillengläsern war man bis jetzt ausschließlich auf das Urteil der Patienten angewiesen, und das war uns so unangenehm, je mehr Arbeit auf die als Dr. von Rosenau's Konstruktionen verwandt worden war. Es konnte sehr wohl.

Figure 16-4

Publication by *Rohr* and *Stock* on anisometropia artificially produced by a contact lens.

Publication of the detailed results of research on anisometropia by and *Moritz von Rohr* and *Wolfgang Stock*: "Über eine Methode zur subjektiven Prüfung von Brillenwirkungen" (*Concerning a Method for the subjective Examination of the Effects of Spectacle glasses*).

(*ROHR* Moritz von, *STOCK* Wolfgang, "Über eine Methode zur subjektiven Prüfung von Brillenwirkungen", *Albrecht von Graefes Archiv für Ophthalmologie*, 83, 1912, 189-205 & 84, 1913, 152-163 - Excerpt of page 189)

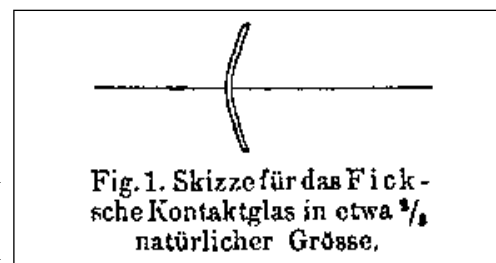


Fig. 1. Skizze für das Fick'sche Kontaktglas in etwa  $\frac{1}{8}$  natürlicher Grösse.

Figure 16-5

Diagram of a Fick-style contact lens according to *Stock* and *Rohr* (1912)

Diagram of a Fick-style contact lens, illustrating the publication of *Stock* and *von Rohr*.

(*ROHR* Moritz von, *STOCK* Wolfgang, "Über eine Methode zur subjektiven Prüfung von Brillenwirkungen", *Albrecht von Graefes Archiv für Ophthalmologie*, 83, 1912, 189-205 & 84, 1913, 152-163 - Figure 1, p. 190)

keratoconus in patients with pronounced astigmatism. They cite large extracts from their publication and they illustrated this with a little diagram of a sagittal cut of a contact lens, which is sometimes attributed to *Fick*:

*“A.E. Fick gives the following description of his invention on page 285. ‘A glass cornea of 8-mm radius of curvature sits with a base of 7-mm radius on the ‘glass-sclera’; the latter is 3 mm wide and corresponds with a sphere of 15-mm radius; the glass cornea is parallel-walled, ground and polished on its outside and inside; likewise, the free edge of the glass sclera is ground and polished; the weight of a ‘Contactbrille’ is about 0.5 g.”*

*“A. E. Fick gibt auf S. 285 seiner Abhandlung die folgende Beschreibung seiner Erfindung. « Eine Glaskornea von 8 mm Krümmungsradius sitzt mit einer Basis von 7 mm Radius auf der ‘Glassclera’; die letztere ist 3 mm breit und entspricht einer Kugel von 15 mm Krümmungsradius ; die Glascornea ist parallelwandig, aussen und innen geschliffen und poliert ; desgleichen ist der freie Rand der Glassklera geschliffen und poliert ; Gewicht einer ‘Contactbrille’ etwa 0,5 g.” (11)*

The authors continue by recalling the contributions of *Kalt*, *Sulzer*’s improvements, and the controversies about the blown or ground nature of the first *Fick* contact shells. They conclude that contact lenses are little used because of the high cost of flawless manufacture:

*“It is of interest to note that the Paris ophthalmologist, E. Kalt, occupied himself independently with the same problem around this time but that A.E. Fick had preceded him in publication. The same method of correction was repeated by D.E. Sulzer some years later, in 1892, the latter drawing attention to an error by A.E. Fick in his publication. Fick’s contact glasses were not of ground glass, as the latter had assumed, but only of blown glass. He himself had had Benzoni of Geneva and the firm of Berthier [sic] of Paris provide excellent contact glasses that were ground from one piece—as emerged from A.E. Fick’s response. One can further learn from Fick’s answer that his first glasses were obtained through E. Abbe and were in fact only blown, and that he later came into possession of ground ‘Contactbrillen’ only through the kindness of the Berlin firm of O. Himmler. His experiments seem to have run aground basically because of the high prices charged for the individual contact glasses, which were 56% higher than the 30 Francs charged for French lenses. You will indeed see nowadays a significant disadvantage in the price, which must be very high for flawless execution but which has hindered the introduction of this very cleverly conceived method of refractive correction.”*

*“Von Interesse ist es, dass sich um dieselbe Zeit der Pariser Ophthalmologe E. Kalt unabhängig mit demselben Problem beschäftigte, dass ihm aber bei der Publikation A.E. Fick zuvorgekommen war. Das gleiche Korrektionsmittel wurde dann einige Jahre später - 1892 - von D.E. Sulzer wieder aufgenommen, der in seiner Veröffentlichung auf einen Irrtum A.E. Fick hinwies. Dessen Kontaktgläser seien nicht geschliffen gewesen, wie er angenommen habe, sondern nur geblasen. Er selber habe gute Kontaktgläser - wie aus A.E. Ficks Antwort hervorgeht, aus einem Stück geschliffenen - von Benzoni aus Genf und von der Firma Berthier (sic) aus Paris herstellend lassen. Aus Ficks Antwort kann man weiter entnehmen, dass seine ersten, durch Vermittlung von E. Abbe bezogene Gläser in der Tat nur geblasen waren, und dass er später allein durch eine Gefälligkeit der Berliner Firma O. Himmler in den Besitz geschliffener Kontaktbrillen gekommen sei. Seine Versuche scheinen besonders an dem hohen Preise der Einzelgläser gescheitert zu sein, der den französischen (von 30 Fr.) um 56 % übertraf. Man wird heute wohl an dem Preise, der bei tadelloser Ausführung sehr hoch ausfallen muss, ein wichtiges Hindernis dafür sehen, dass sich dieses so scharfsinnig erdachte Korrektionsmittel nicht besser eingeführt hat.” (12)*

### **The Specifications of a Contact Lens**

The authors explain the corrective power of contact lenses in very technical language:

*“As we see from the description, we are considering a highly curved lens, the inner surface of which has the apical curvature of the front corneal surface, so that it lies very closely on it. If we apply this means of correction to axial ametropia, we are able to*



*reach the condition of emmetropia through the introduction of an appropriately ametropic curvature. Nothing changes when the eyes turn and therefore look in different directions of regard; however, the refraction of the optical system will have a different value in the corrected eye and the cardinal points will change their position.”*

*“Wie man aus der Beschreibung sieht, handelt es sich dabei um eine stark durchgebogene Linse, deren Innenfläche die Scheitelkrümmung der vorderen Hornhautfläche erhält, so dass sie sich eng an sie anlegt. Verwendet man dieses Mittel zur Korrektur von Achsenametropien, so liegt es auf der Hand, dass man dann durch Einführung einer geeigneten Krümmungsmetropie den emmetropischen Zustand erreicht. An der Augendrehung und somit an dem Blickwinkel wird nichts geändert, dagegen wird die Brechkraft des optischen Systems im korrigierten Auge einen abweichenden Wert erhalten, und auch die Kardinalpunkte werden eine Verlagerung erfahren.” (12)*

### **The Optical Theory of Contact Lenses**

Taking the *Gullstrand* theoretical eye into consideration and using formulae from physics and mathematics, the authors consider that optical explanations are too complicated for readers of the review. The readers are therefore referred to descriptions of the theory of spectacles, a theory supposedly known by this audience (13), and the authors limit themselves to emphasizing the differences between theories of spectacles and contact lenses. The specificity of contact lens optics systems come from the fact that, as soon as contact lenses are placed on the eye, they form a single optical system with the latter, aside from a significant lengthening of the system by 0.40 mm, which corresponds with the thickness of the glass. This 0.40-mm difference has been studied and explained in great detail:

*“The high curvature of the two lens surfaces has the additional effect that an afocal contact glass does not leave the retinal image unchanged [...]. The front radius  $r_1$  of this afocal system is derived from the back radius  $r_2$ , the thickness  $d$ , and the refractive index  $n$  [...], and the system thus formed functions in the manner of a thin Steinheil's cone, with the magnification constant of  $V = 1.02$ .”*

*“Die starke Durchbiegung der beiden Linsenflächen hat auch zur Folge, dass ein afokales Kontaktglas, das Netzhautbild nicht ungeändert lässt [...]. Der Vorderradius  $r_1$  dieses afokalen Systems ergibt sich aus dem Hinterradius  $r_2$  der Dicke  $d$  und dem Brechungsindex  $n$  [...] und das so gebildete System wirkt nach Art eines dünnen Steinheilschen Conus, mit der Vergrößerungsziffer  $V = 1,02$ .” (14)*

The authors go on to explain that a contact lens of 0.40 mm in thickness and a refractive power of 1.00 dioptre would not have any effect on the size of the retinal image: *“According to the graphic representation, a corrective Fick's 'Kontaktbrille' of 0.4 mm in thickness does not then change the size of the retinal image, if the refractive power of  $D$  is 1.00 diopter.” (18)*

### **Insertion of a Corneal Contact Lens**

The experiments were carried out on *von Rohr's* eye, which was  $-6.00$  diopters myopic. The lenses were worn after local anesthesia for periods of half an hour:

*“First, the right eye of Mr. von Rohr (ametropia =  $-6,00$  diopters) was made emmetropic by insertion of a Fick's 'Kontaktbrille.' In our experiments and because of manufacturing difficulty we limited ourselves to the optically effective portion of the 'Kontaktbrille,' known as the 'glass cornea' in Fick's terminology. We proceeded with the insertion as follows: with the observer sitting in a chair with the head in a horizontal position and directing the eye to be fitted straight down after*

*instilling cocaine drops, while he pulled his lower lid away. When we had filled the contact glass with physiological saline solution, we pressed it onto the cornea from below, with the eye looking vertically downwards.”*

*“Es wurde zunächst das rechte Auge M. v. Rohr (A= -6,0 dptr) durch Aufsetzen einer Fickschen Kontaktbrille emmetropisch gemacht. Wegen der Schwierigkeit der Herstellung beschränkten wir uns bei unseren Versuchen mit dem optisch wirksamen Teil der Kontaktbrille, der Glascornea in der Fickschen Ausdrucksweise.*

*« Wir gingen beim Aufsetzen so vor, dass der auf einem Stuhle sitzende Beobachter bei horizontaler Haltung des Kopfes das zu bewaffnende Auge nach der Einträufelung von Kokain direkt nach unten richtete, während er sein Unterlid herabzog. Alsdann füllte man das Kontaktglas mit physiologischer Kochsalzlösung und drückte es dem Beobachter von unten her an die Cornea des senkrecht herabblickenden Auges an.” (16)*

It is important to emphasize that, during this period of history, Zeiss had experienced difficulty in manufacturing scleral contact lenses. The experiments were carried out only with the “glass cornea of Fick’s terminology”. Thus, corneal contact lenses were being used, although their diameters were not given in publications.

After having corrected his -6.00 diopters of myopia, von Rohr had inserted a new contact lens in his own eye sufficient to make him hyperopic on one side in order to reproduce the optical conditions of unilateral aphakia. These experiments were subsequently repeated on the eyes of Stock and of his two assistants at the Jena Eye Clinic, Erggelet and Ishihara.

This work is, for the most part, discussed by its authors in the course of congresses and has been summarized in other publications. (17) Contact lenses thus acquired public recognition in this way and became well known as useful devices for scientific purposes in studies on physiological optics.

### 1.3 – Erggelet’s Study on Unilateral Aphakia (1913)

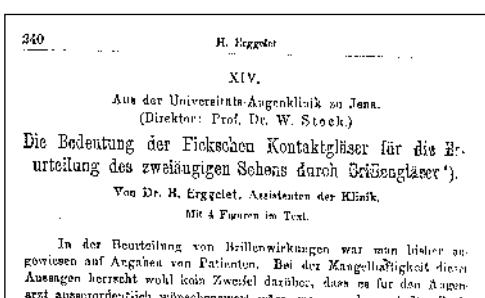


Figure 16-6

Erggelet’s publication on the use of contact lenses in the study of binocular vision in anisometropia. Erggelet’s publication was entitled “Die Bedeutung der Fickschen Kontaktgläser für die Beurteilung des zweiäugigen Sehens durch Brillengläser” (The Significance of Fick’s Contact glasses for the Assessment of binocular Vision by means of Spectacle glasses) and concerned the effect of glasses on eyes rendered anisometric by a unilateral contact lens.

(ERGGELET Heinrich “Die Bedeutung der Fickschen Kontaktgläser für die Beurteilung des zweiäugigen Sehens durch Brillengläser”, Klinische Monatsblätter für Augenheilkunde, 52, 1914, 240-246 - Excerpt of page 240)

#### Artificial Anisometropia Produced by Contact Lenses

In the years that followed, Erggelet, assistant at the Ophthalmological Clinic in Jena, presented two other studies concerning artificial ametropia produced by contact lenses:

The first publication dealt with unilateral aphakia: “Zur Korrektur der einseitigen Aphakie” (Concerning the Correction of unilateral Aphakia). (18) The second publication concerned binocular vision in anisometropia: “Die Bedeutung der Fickschen Kontaktgläser für die Beurteilung des zweiäugigen Sehens durch Brillengläser” (The Significance of Fick’s Contact Glasses for the Assessment of Binocular Vision by Means of Spectacle glasses). (19)

In producing a hypermetropia of +13 diopters with a ground “*Fick’s contact lens*” in his emmetropic eye, the author placed himself under the same optical conditions as a unilateral aphakic person:

*“I gave my right eye, which is emmetropic and has a normal visual acuity, a hyperopia of 13.0 dioptres by means of a Fick contact glass; as a result, it became, so to speak, an aphakic eye for distance vision.”*

*“Durch ein Ficksches Kontaktglas wurde meinem rechten Auge, das wie das rechte emmetropisch ist und normalen Visus besitzt, eine Hyperopie von 13,0 dptr gegeben; es wurde dadurch gewissermassen für die Ferne aphakisch.”* (20)

Thus, in verifying the optical features of anisometropia experimentally, he explains the failure of prescribed spectacle glasses to correct them:

*“The contact glass experiments are particularly interesting and instructive because they make it possible to allow the subject to react simultaneously to all of the characteristic conditions of seeing with glasses.”*

*“Die Kontaktglasversuche sind mit deshalb so interessant und lehrreich, weil sie es ermöglichen, die ganze eigenartigen Verhältnisse des Sehens unter der Brille gleichzeitig auf den Beobachter einwirken zu lassen.”* (21)

The principle of “*Fick’s contact lenses*” still seemed relatively unknown, as the author felt himself once again obligated to provide a detailed description of that principle at the conclusion of his article.

## 1.4 – Ishihara’s Study on Anisometric Myopia using Contact Lenses (1914, 1925)

On the eve of World War One, the Japanese ophthalmologist *Ishihara*, then established in Professor *Stock’s* clinic at Jena, revisited, without completely resolving, the problem of intolerance of their spectacle glass correction by anisometropes in a publication entitled “***Warum können Anisometropen höheren Grades in der Regel die Vollkorrigierenden Gläser nicht ertragen?***” (*Why can higher level Anisometropes generally not tolerate their full Glasses Correction?*). He made himself unilaterally myopic (i.e., anisometric) by using -3.00 and -5.00 diopter lenses. He employed a set of six contact lenses that had been custom ground by *Zeiss* for this purpose:

*“After that, I made myself anisometric with the help of Fick’s contact glasses. These contact*

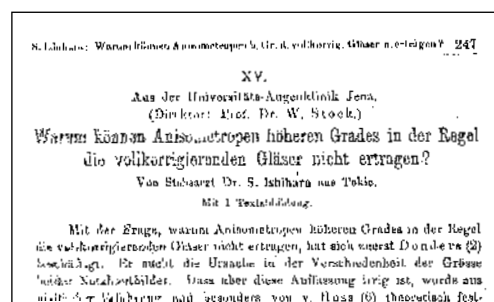


Figure 16-7

*Ishihara’s publication on his research on artificial anisometropia produced with the aid of contact lenses (1914).*

*During his role as assistant at the Ophthalmological Clinic in Jena, Shinobu Ishihara published the results of his research carried out on his own eyes concerning anisometropia produced by contact lenses: “Warum können Anisometropen höheren Grades in der Regel die Vollkorrigierenden Gläser nicht ertragen?” (Why can higher level Anisometropes generally not tolerate their full Glasses Correction?).*

(ISHIHARA Shinobu “Warum können Anisometropen höheren Grades in der Regel die Vollkorrigierende Gläser nicht ertragen?”, *Klinische Monatsblätter für Augenheilkunde*, 52, 1914, 247-252 - Excerpt of page 247)

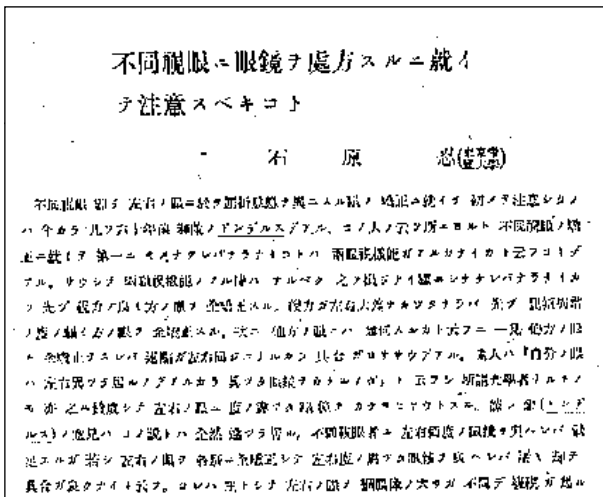


Figure 16-8

Japanese language publications by Shinobu Ishihara concerning his research experiments on artificial anisometropia produced by means of contact lenses (1925).

On his return to Japan, Shinobu Ishihara published in his mother tongue the work he did at Jena: "Note on spectacle prescription for anisometropia."

(ISHIHARA Shinobu "Notes on spectacle prescription for anisometropia" (in Japanese) Nippon Ganka Gakkai Zasshi (Acta Societatis Ophthalmologicae Japonicae) 30, 1925, 7-9 - Page 7)

glasses were provided for me by the firm C. Zeiss. I had a total of six contact glasses ground specially for my eyes at my disposal."

"Nachdem ich mit Hilfe von Fickschen Kontaktgläsern selbst zum Anisometropen gemacht war. Diese Kontaktgläser wurden für mich von der Firma C. Zeiss angefertigt, Es standen mir im ganzen sechs besonders für meine Augen geschliffene Kontaktgläser zur Verfügung." (22)

Ishihara succeeded in wearing these contact lenses for up to 30 minutes at a time, starting with local cocaine anesthesia and later without cocaine. When he returned to Japan, he had a short synopsis of his work published in Japanese with the title "Note on spectacle prescription for anisometropia." (23)

### 1.5 – Binocular Vision in Anisometropes (Erggelet 1916)

In 1916, *Erggelet* published a new study on binocular vision problems in anisometropes caused by their total correction by spectacle glasses: "*Ein Beitrag zur Frage der Anisometropie*" (*A Contribution concerning the question of anisometropia*). (24)

By means of experiments on his own eyes, in which he used a stereoscope of his own invention and fitted one eye with a ground contact lens, he showed that the difficulty of the correction of anisometropia by spectacle glasses was not due solely to the difference in size of retinal images, as had been previously believed, but was also due to the prismatic deviation of spectacle glasses, which interfered with the fusion of retinal images.

### 1.6 – The Conclusion of the Anisometropia Studies (Erggelet 1921, Rohr 1922)

After World War One, *Erggelet* repeated the experiments on artificial anisometropia, using *Zeiss* corneal contact lenses: "*Versuche zur beidäugigen Tiefenwahrnehmung bei hoher Ungleichsichtigkeit*" (*Experiments on Binocular Depth Perception in cases of severe Anisometropia*). He advanced new clarifications on stereoscopic vision concerning modifications of spatial sense and depth perception in the unilateral aphake who had been corrected with spectacle glasses. However, he also complained of difficulties encountered with the ground contact lenses of corneal diameter:

"Unfortunately there was only one glass cornea without a scleral portion as adhesion

*glass at my disposal. Because this must be a divergent meniscus, it has to be thicker at the edge than at the center and forms a step. The lids knock against this very frequently and displace the glass with blinking.”*

*“Es stand leider nur eine Glashornhaut ohne Lederhautteil als Haftglas zur Verfügung. Da dieses ein zerstreuer Meniskus sein muss, so ist er am Rand dicker als in der Mitte und bildet eine Stufe. An dieser stossen sehr leicht die Lider an und verschieben das Glas beim Blinzeln häufig.” (25)*

In the course of presentations that he made across Europe in order to publicize anisometric spectacles, *von Rohr* was led to recall his experiments with contact glasses. Thus, in a lecture given in London on the theme **“On the Available Means for correcting Cases of considerable Anisometropia,”** he stated:

*“As we were experimenting at that time with Fick’s contact glasses, it occurred to me that I might correct one of my own eyes (each having nearly – 7 D) by means of a suitable contact glass.*

*He [Erggelet] used a contact glass for this purpose and was able to wear it for some time, from 25 to 30 minutes. In 1913, we could make these contact glasses in a primitive form only, so that the movement of the eyelid sometimes dislodged the contact glass. However, to form a general impression, these contact glasses answered well enough.” (26)*

Contact glasses were therefore used for studies in theoretical optics. The clinical applications of contact lenses were actually envisaged only some years later. (27)

## 2 - Discussion

In the course of analyzing publications on studies of physiological optics, one can appreciate that most aspects linked to the manufacture of contact lenses, including fitting, manipulation, and tolerance, are addressed in them, without, however, being their main subject.

### Contact Lens Theory

Paradoxically, it is the studies on spectacle glasses or rather the failure of correction by these devices that have given these authors the opportunity to study and explain the theory of contact systems. The optical and mathematical theory of contact lenses had never been addressed previously, whereas authors were content to explain their effectiveness in keratoconus on the basis of lacrimal neutralization of corneal irregularities. Engineers and their colleagues at *Zeiss* abandoned this line of reasoning. They disregarded tears and lacrimal physiology and reasoned only in terms of the physics of the modifications produced by the juxtaposition of a glass plate with a given index of refraction on a globe with the physical characteristics described by *Gullstrand*. It is true that they placed contact lenses on non-pathological eyes with a regularly spherical cornea and not on a cornea with keratoconus or corneal astigmatism.

### Terminology: from “Kontaktbrille” to “Haftglas”

<b>Author</b>	<b>Terminology</b>
<i>Michel (1893)</i>	<i>Sulzer'schen Contactglas (Sulzer's contact glass)</i>
<i>Stock (1912)</i>	<i>von Fick angegebenen Kontaktbrillen ("Contact spectacles" introduced by Fick)</i>
<i>Rohr &amp; Stock (1912/13)</i>	<i>Fick'sches Kontaktglas (Fick's contact glass), Kontaktglas (Contact glass)</i>
<i>Rohr &amp; Stock (1913)</i>	<i>Kontaktbrille (Contact spectacle), Ficksche Kontaktbrille (Fick's contact spectacle), Ficksche Kontaktglas (Fick's contact glass), Kontaktglas (Contact glass)</i>
<i>Erggelet (1913/14)</i>	<i>Ficksche Kontaktglas (Fick's contact glass)</i>
<i>Erggelet (1914)</i>	<i>Ficksche Kontaktglas, (Fick's contact glass) Kontaktglas (Contact glass)</i>
<i>Ishihara (1914 &amp; 1925)</i>	<i>Ficksche Kontaktglas, (Fick's contact glass) Kontaktglas (Contact glass, contact lens)</i>
<i>Erggelet (1921)</i>	<i>Ficksche Haftglas (Fick's adhesion glass) Haftglas, (Adhesion-glass, adhesion lens)</i>

Table 16 - 2  
Terminology of contact lenses at the time of their use for experiments in physiological optics.

In 1893, *Michel* designated the contact lens used for his experiments as a *Sulzer's* glass, which provoked *Fick's* protest and his claim of paternity.

In 1912, the first publications from Jena paid homage to the work of *Fick*, large extracts of whose work were cited and whose terminology was used in “Kontaktbrille” (contact spectacle).

In the years that followed, the term “*Fick's* contact glass” (*Ficksche* Kontaktglas) prevailed, then simply “contact glass” (Kontaktglas).

The last publications of *Erggelet* (1921) utilized the term “adhesion glass” or “adhesion lens” (Haftglas) which was advocated by *Zeiss* at the time of the commercialization of the first ground scleral contact lenses during this era.

We have observed an evolution of the terminology over a decade, from the use of that unsuitable expression “Kontaktbrille” (contact spectacle) to the more conventional term of “contact glass” (verre de contact) advocated in France by *Sulzer* (1892). Around 1920, *Zeiss* used the term “overlay-glass” (Auflageglas) then “adhesion-glass” or “adhesion

lens” (Haftglas), which this firm tried to impose in Germany with the purpose of identifying the ground contact lenses that it manufactured.

### **Dimensions of Contact Lenses**

Authors have used ground contact lenses for their studies. We learn that “*These do not stay at a certain distance from the eye like normal spectacle lenses, but their back surface lies on the cornea, as the name signifies*” (28) and “*As one can see from the description, we are considering a lens of high curvature, the back surface of which corresponds with the apical curvature of the front corneal surface, so that it lies closely up against it.*” (29).

Several publications mention that the contact lenses utilized for these experiments were missing their scleral peripheral portions: “*There was unfortunately only one ‘glass cornea’ without a scleral component available at my disposal as a ‘adhesion glass.’*” (30) The difficulties in the manufacture of a scleral contact lens (i.e., one provided with two curvatures, one for the corneal part, the other for the scleral) seemed still insurmountable during this era. Experiments were therefore conducted with lenses corresponding solely with the corneal part, i.e., “glass cornea”, in Fick’s terminology: “*On account of the difficulty of manufacture, we limited ourselves in our experiments to the optically effective component of the ‘Kontaktbrille,’ i.e., the ‘glass-cornea’ of Fick’s expression.*” (31)

### **Contact Lens Fitting**

Authors have chosen the “parallel fitting”, by which they have researched a curvature identical to that of the front surface of the cornea for the back surface of contact lenses. The tear meniscus situated between the eye and the lens, also having a parallel surface, no longer plays any optical role, the refractive effect being reached by the ground magnitude of curvature of the front lens surface. This choice of a lens reduced to the corneal portion, with a back radius identical to that of the cornea and a ground front radius with refractive effect, is an original step that is very different from that used at the same period of time for blown contact shells.

Before insertion, the eye was anesthetized with cocaine. Some authors, such as Ishihara, judged that this was no longer necessary after a certain training period: “*The lenses sit well and do not disturb the movement of the eyes. To begin with, I could insert and remove them with the help of instilled cocaine drops and then after some practice very easily do without these.*” (32) For insertion, the subject, sitting on a chair, lowered the inferior eyelid and placed the contact lenses, filled with physiological saline solution, on the surface of the eye, which was directed downwards. The contact lenses generally adhered right away, without interposition of air bubbles. If necessary, some movements of centration were necessary. The contact lenses were mobilized at the time of eye blinking but did not interfere with ocular mobility: “*Generally, the contact glass adhered well and right away, i.e., without air bubbles and only small movements were necessary to achieve good centration.*” (33)

In fact, tolerance for contact lenses was not perfect: “*Through the wearing of contact glasses, I experienced local inflammatory symptoms at the beginning, namely, conjunctival injection, a foreign body sensation, photophobia, epiphora, etc. After about ten days of practice I was able to wear them without much discomfort for up to 30 minutes.*” (34) The experiments rarely lasted 40 to 50 minutes by reason of local

irritations, the symptoms of which disappeared 10 to 20 minutes after removal of the lenses: *“The experiments were discontinued after 40-50 minutes on account of increasing local irritations. In 10 to 20 minutes all symptoms diminished.”* (35) It is necessary to take into account the fact that the researchers used monocurved corneal contact lenses with a relatively wide diameter. Owing to this fact, they would frequently hit the palpebral border, irritating the limbus and easily decentering with each blink, as *Erggelet* describes: *“Because this is a concave meniscus, the edge is thicker than in the middle and makes a step. Against this edge, the lids easily hit the lens and frequently move it during blinking.”* (36)

### **Optical Correction**

The authors indicate that these lenses may be used for the correction of myopia: *“A myope of normal visual acuity obtains, at least theoretically, a higher visual acuity by means of ‘Kontaktbrille’ correction than an emmetrope because of the change of the axis of his eye.”* (37) The right eye of *Rohr* was corrected in this way. He was a myope of  $-6.00$  diopters. Conversely, the same system could be used to create an artificial ametropia in a normally sighted eye, especially for studies of the correction of anisometropia by means of spectacle lenses: *“Originally they were destined for the correction of refractive errors. Refractive errors can, however, be created with their help.”* (38)

### **Appreciation of Corneal Contact Lenses**

Although the toleration for these contact lenses of corneal diameter was limited to the duration of the corneal anesthesia, the value of their optical correction was appreciated. The authors regretted their commercial failure and the obstacle to their wider dissemination due to their high price of manufacture: *“One will indeed see today a significant disadvantage in the price, which must be very high for flawless execution but which has hindered the introduction of this very cleverly conceived method of correction.”* (39)



### 3 - A short History on the Citations, Omissions and Misinterpretations

#### Citations and Omissions

The history of corneal contact lenses that were used in Jena for studies in physiological optics is rarely recalled in the manner I have just described. Numerous authors suppress this phase of corneal contact lenses being used for experiments in physiological optics or they limit themselves to citing the first publication of *Rohr* and *Stock*.

#### Confusions between Corneal Contact Lenses and Scleral Contact Lenses

The most habitual error consists of confusing the ground corneal lenses used experimentally in physiological optics with the first series of ground lenses, commercialized after 1920 by *Zeiss*. Thus, *Mann*, often quoted, writes in 1938: “*The first Zeiss glass was ground in 1911, and since that time this firm has specialized in producing ground glasses of all curves. The earliest Zeiss glasses were afocal, and the curve required to correct the ametropia was calculated after measuring the corneal radii with an ophthalmometer.*” (40) In the same way, *Mandell* clarifies: “*Glass contact lenses were made by Karl Zeiss Optical Works in Jena and described in 1912 and 1923 as ground and polished. A trial set of lenses with four posterior radii was available.*” (41) There is evidently confusion on the part of these authors between contact lenses of corneal diameter used for experiments in physiological optics, ground in 1912 for the eyes of *von Rohr* and *Stock* then for *Erggelet* and *Ishihara*, and the ground scleral contact lenses of later manufacture for the correction of keratoconus. The latter were afocal lenses and were commercialized by *Zeiss* starting in 1920 with a set of three, then four, trial lenses. (42)

#### The Postulated Keratoconus of Stock

A curious error consists of claiming that *Stock* had been affected by keratoconus and that he had taken the initiative in 1912 of asking *Zeiss* to manufacture contact lenses to correct his own refractive error: “*So far as can be traced, there were no further developments of any note until 1912, when Dr. W. Stock, himself a sufferer of keratokonus, reported a great improvement in his vision with Fick ground contact lenses made by Zeiss. In 1920 he suggested to Zeiss a specification for their first fitting set, intended only for the correction of keratoconus.*” (43)

#### Partial or Total Omission

In his argument in favor of the anteriority of corneal contact lenses, *Graham* cited studies by *von Rohr* and *Stock* but omitted to cite those of *Erggelet* and *Ishihara*. (44) This omission commonly occurs in articles and books written by English-speaking authors and may be partially explained by their relatively poorer access to original documents. (45) For *Duke-Elder* and those who took inspiration from his *System of Ophthalmology*, there would appear to exist a hiatus of sixty years in the history of corneal contact lenses between the *Kalt* lenses and the *Tuohy* plastic corneal lenses in 1948, “*the virtually ‘corneal’ in dimension (Kalt, 1888). It was not until 1948 that Tuohy in America produced an all-plastic corneal lens.*” (46) This neglect of the *Zeiss* studies in the years around 1912, or, more frequently, a vague reference in an ambiguous sentence is frequently repeated. (47)

## Conclusion

Starting in 1912, researchers at the *Zeiss Optical Factory* in Jena and physicians at the *Ophthalmology Clinic in Jena* were using contact lenses that possessed some of the geometric characteristics of present-day corneal contact lenses. The researchers did not provide them with any scleral rim and they were content to use the corneal part only. This was because of the difficulties of grinding a bi-curved shell. Consequently, it was a question of responding to the requirements of research with ground and surfaced 'corneal contact lenses,' namely for the short-term production of artificially produced refractive errors to be used in experiments on patient tolerance of corrective glasses.

It is probable that the back surface of these corneal contact lenses had a single curvature that was matched with the keratometric readings of the user's cornea. It seems that these researchers had no precise data on corneal topography or, particularly, the peripheral flattening of the cornea. In any event, they do not refer to the introduction of this flattening in the peripheral zone of the lenses. The authors do make reference to the discomfort experienced with the wearing of these lenses and attribute this, correctly, to the thickness and the jump at the periphery. The grinding of these lenses was probably fraught with difficulty. The nature of glass, which was the only available material at this time, made them heavy and thick, thus preventing them from being worn for longer than half an hour. These disadvantages and a cost that was considered exorbitant prevented their successful commercialization.

## Notes

- 1 For Woinow's use of the orthoscope in 1869, see chapter IX: *The Era of Orthoscopes*.
- 2 Michel 1893, p. 233.
- 3 "Einen willkommenen Ersatz für das Woinowische Orthoscop, mit dem ich mich drei Mal ziemlich erfolglos abmühte, fand ich in einem Contactglas nach Sulzer, welches von Strübin in Basel angefertigt und von Hrn. Prof. Pflüger mir zur Verfügung gestellt wurde." (Michel 1892, p. 56)
- 4 Michel 1892, p. 56.
- 5 The reference to "Sulzer's contact lenses" might have led one to suppose erroneously that it involved ground contact lenses supplied by one of the opticians cited by the latter, *Benzoni* of Geneva or *Benoit-Berthiot* of Paris.
- 6 Fick 1894, p. 128. See also chapter XIII: *The Decades after the Invention*.
- 7 Stock 1912, p. 198. Communication to the 38th Congress of the German Ophthalmological Society (38. Versammlung der Deutschen Ophthalmologischen Gesellschaft) in Heidelberg. The oral presentation summarizes the article that was published in collaboration with von Rohr in *Graefe's Archiv für Augenheilkunde*. (Rohr & Stock, 1912 & 1913).
- 8 Rohr & Stock, 1912 & 1913 (The publication is divided between the volumes for two successive years).
- 9 "Um die Refraktion des optischen Systems im Auge nach Belieben zu ändern ohne doch die charakteristische Bewegung des ganzen Systems um den Augendrehpunkt zu beeinflussen". (Rohr & Stock 1912, p. 190).
- 10 "Die nähere Geschichte der Kontaktbrillen scheint nicht allgemein bekannt zu sein, sie ist aber so interessant, dass es sich wohl lohnt, sie hier mit einigen Worten mitzuteilen." (Rohr & Stock 1912, p. 190).
- 11 Rohr & Stock 1912, p. 190-191.
- 12 Rohr & Stock 1912, p. 191.
- 13 It is described by Rohr in: "Die Brille als optisches Instrument" (*The Spectacle as optical Instrument*), Graefe-Saemisch Handbuch der gesamten Augenheilkunde, 2. Aufl, p. 14-16.
- 14 Rohr & Stock 1912, p. 195.
- 15 "Nach der graphischen Darstellung ändert eine korrigierende Ficksche Kontaktbrille mit der Dicke von 0,4 mm nur dann die Grösse des Netzhautbildes nicht, wenn sie eine Brechkraft von  $D1 = 1 \text{ dptr}$  hat." (Rohr & Stock 1912, p. 197).
- 16 Rohr & Stock 1912, p. 197.
- 17 Including Rohr & Stock 1913/14.
- 18 Erggelet 1913/14.
- 19 Erggelet 1914. Communication presented on November 2, 1913, at Halle an der Saale, at the meeting of the *Association of the Ophthalmologists of Province of Sachsen-Anhalt and the State of Thüringen (Vereinigung der Augenärzte der Provinz Sachsen-Anhalt und des Thüringer Landes)*.
- 20 Erggelet 1913/14, p. 33.
- 21 Erggelet 1914, p. 244.
- 22 Ishihara 1914, p. 247.
- 23 Ishihara, 1925. (I thank Professor Saishi Mishima for verifying the reference usually dated 1926 erroneously, following an error by Mizutani in 1966).
- 24 Erggelet, 1916/a. Publication in *Zeitschrift für Sinnesphysiologie* and a summary by Erggelet himself in *Zeitschrift für ophthalmologische Optik* (Erggelet 1916/b).
- 25 Erggelet 1921/a, p. 686. - Communication at Jena on 02.03.1921, published in the same year; see also an analysis of this publication by Rohr (1921/a).
- 26 Rohr 1922/23, p. 94 & 95.
- 27 For the university clinics that have participated in the trials and for the first commercially available contact lenses for the correction of keratoconus, see chapter XVIII: *Early Ground Contact Lenses*. Zeiss commercialized contact lenses for the correction of other errors of refraction starting from 1930.
- 28 "Diese stehen nicht wie die gewöhnlichen Brillengläser in einiger Entfernung vor dem Auge, sondern ihre Innenfläsche liegt, wie der Nahnme andeutet, der Kornea an." (Erggelet 1914, p. 240).
- 29 "Wie man aus der Beschreibung sieht, handelt es sich dabei um eine stark durchgebogene Linse, deren Innenfläche die Scheitelkrümmung der vorderen Hornhautfläche erhält, so dass sie sich eng an sie anlegt." (Rohr & Stock 1912, p. 191).
- 30 "Es stand leider nur eine Glashornhaut ohne Lederhautteil als Haftglas zur Verfügung." (Erggelet 1921, p. 686).
- 31 "Wegen der Schwierigkeit der Herstellung beschränkten wir uns bei unseren Versuchen mit dem optisch wirksamen Teil der Kontaktbrille, der Glaskornea in der Fickschen Ausdruckweise." (Rohr & Stock 1912, p. 197).
- 32 "Die Gläser sitzen gut, ohne die Augenbewegungen zu stören. Zuerst konnte ich sie mit Hilfe der Kokaineinträufelung und dann nach einiger Uebung ohne diese sehr leicht auf- und ablegen." (Ishihara 1914, p. 247).
- 33 "Es haftete meistens gleich gut, d.h. ohne Luftblasen, und es bedurfte nur geringe Verschiebungen, um einen zentrierten Sitz herbeizuführen." (Rohr & Stock 1912, p. 197).
- 34 "Durch das Tragen der Kontaktgläser bekam ich anfangs bald lokale Reizerscheinungen, nämlich: konjunktivale Injection, Fremdkörpergefühl, Lichtscheu, Tränenfluss, usw. Nach etwa zehntägiger Uebung konnte ich sie ohne merkliche Störung bis zu 30 Minuten lang tragen." (Ishihara 1914, p. 248).
- 35 "Die Versuche wurden wegen der zunehmenden lokalen Reizerscheinungen nach 40-50 Minuten abgebrochen. In 10-20 Minuten gingen alle Symptome zurück." (Ishihara 1914, p. 248).
- 36 "Da dieses ein zerstreuer Meniskus sein muss, so ist er am Rand dicker als in der Mitte und bildet eine Stufe. An dieser stossen sehr leicht die Lider an und verschieben das Glas beim Blinzeln häufig." (Erggelet 1921, p. 686).
- 37 "Ein Myoper von normaler Sehschärfe erhält - theoretisch wenigstens - infolge der Achsenveränderung seines Auges durch die Korrektion mit der Kontaktbrille eine höhere Sehschärfe als ein Emmetrop mit derselben Sehschärfe." (Rohr & Stock 1912, p. 196).
- 38 "Ursprünglich waren sie bestimmt zur Korrektion von Refraktionsanomalien. Es lassen sich jedoch mit ihrer Hilfe auch Ametropien erzeugen." (Erggelet 1914, p. 240).
- 39 "Man wird wohl an dem Preise, der bei tadelloser Ausführung sehr hoch ausfallen muss, ein wichtiges Hindernis dafür sehen, dass sich dieses so scharfsinnig erdachte Korrektionsmittel nicht besser eingeführt hat." (Rohr & Stock 1912, p. 191).
- 40 Mann 1938, p. 113.
- 41 Mandell 1980, p. 11.
- 42 See chapter XVIII: *Early Ground Contact Lenses*.
- 43 Dickinson, 1946, p. 18.
- 44 Graham 1959, p. 63-64.
- 45 The error is found also in certain German-speaking authors, as in Baron (1981), who misspells the family name "Stock," converting it to "Stork," incorrectly assigning these lenses for the correction of astigmatism.
- 46 Mackie in Duke-Elder 1970, p. 735. Note also the mistaken attribution of the use in 1888 of a corneal diameter contact lens to Kalt. See chapter XI: *Eugène Kalt's Optical Treatment of Keratoconus*.
- 47 Thus in Györfy, 1994.

